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Optical Properties of ZnSe/ZnCdSe Superlattices studied by Spectroscopic Ellipsometry

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ABSTRACT

We modeled spectroscopic ellipsometry data to characterize the optical constants of a series of ZnSe/Zn(1-x)Cd(x)Se/ZnSe superlattices on GaAs, in order to quantify the thickness-dependent effects of strain and quantum confinement on the critical-point transitions in ZnCdSe. In our model, we used table values and our own data collected from bulk samples for the dielectric functions of ZnSe and ZnCdSe respectively, allowing the latter to vary to account for the aforementioned effects. Our modeling techniques failed to produce an adequate fit for any of the superlattice samples.

INTRODUCTION

There has been much interest of late in the use of ZnSe and ZnCdSe semiconductor films in a variety of optical applications, including blue-green laser diodes. Ample work has been done in finding the optical spectra of these materials. However, new devices have utilized a superlattice, or periodic structure alternating layer upon later, of the two materials. The optical properties of the materials in superlattice may differ from bulk due to strain (a biaxial force owing to a slight difference in the lattice constants of the materials) and quantum containment (an electron being confined in the layer with the lower bandgap and thus minimum potential energy) effects, which should be present in a superlattice structure.

More work is needed to quantify the effects of strain and quantum confinement in these structures; to our knowledge, no one to this date has treated the subject in a comprehensive way. The purpose of this work is to find some functionality between the thickness of the ZnCdSe layers and the change in their critical-point transitions compared to a bulk sample, the properties of which we characterized prior to the superlattice work and in fact used as a starting point in the superlattice modeling.

Spectroscopic ellipsometry is a powerful, non-destructive technique for characterizing the optical constants of a variety of materials and especially of semiconductors. Ellipsometry is especially suited to this application because it takes data across the optical spectrum, rather than at discrete wavelengths, and thereby can quantify changes in critical-point energies.

However, spectroscopic ellipsometry does not measure the dielectric function directly; rather it measures two quantities, ✈ and ☽, related to the change in polarization of a beam of light reflected from the sample. Since these quantities are dependent upon the dielectric function and physical structure of the sample, the task of the researcher is to provide a model that theoretically reproduces the experimental ✈ and ☽ spectra. This modeling is relatively straightforward for a simple sample (for example, a thin film on a substrate), but can become complex for a more complicated sample, such as a superlattice of two different materials. The difficulties of this approach will be detailed in the next section.

EXPERIMENTAL DETAILS

The superlattices were grown by molecular-beam epitaxy (MBE) at the University of Notre Dame. MBE is known to produce high-quality, homogenous crystalline structures. Another benefit is that its results are consistent. Two nominally identical layers grown by the same machine on the same day will be effectively identical in thickness, although that actual thickness may differ from the nominal value. This invariability is crucial to our model.
We used a J.A. Woollam commercial spectroscopic ellipsometer. Data was collected every nanometer from 2 to 6 eV at the angles of incidence 65, 70 and 75 degrees.

In ellipsometry, one measures two standard parameters, ✈ and ☽, at each wavelength of the spectrum. The task of the researcher is to find a dielectric function for each layer of the sample that, given what is known physically about the sample (layer thickness, presence of a native oxide, et cetera) reproduces the experimental ✈ and ☽over the entire measured energy range.

To find how the dielectric function of the ZnCdSe varied with the thickness of the superlattice layers, we attempted to characterize two series of superlattice samples; within each series the composition of the ZnCdSe layers and the thicknesses of the layers relative to one another was held constant; the absolute thicknesses and the number of the layers varied between the three samples in each series. We also attempted to characterize a single superlattice with much thinner layers. A summary of the samples we chose is presented in Table 1.
As a starting point, we analyzed bulk samples of ZnCdSe on GaAs at the same compositions (percent cadmium) as in the superlattices. This was done for two reasons; first, to provide starting values for the dielectric function of the superlattice ZnCdSe layers which we could insert into our superlattice model and vary to produce a fit; and second, so we could compare the superlattice layers to a bulk sample. A sample fit for bulk ZnCdSe is shown in Graph1.

When modeling a superstructure, one must be correct as to the thicknesses and dielectric properties of the constituent layers, as well as the thickness and composition of any surface oxide.

We used table values for the optical properties of the GaAs substrate. The dielectric function for ZnSe was taken from Sivananthan et al. The properties of the overlayer were taken from Koo et al. To find the actual thicknesses of the layers, we used the nominal thicknesses as a starting point and did a least-squares fit.

At this point in our analysis, the only thing left to fit was the dielectric function of the ZnCdSe layers above the bandgap. We started with the parametric oscillator model from the bulk ZnCdSe sample of the appropriate composition, and allowed the oscillator positions and parameters to vary, both by manually and with the built-in fitting tool. However, we failed to produce a model whose ✈ and ☽ spectra matched the experiment in the absorption region.

RESULTS AND CONCLUSIONS

Since we could not find a fit for any reasonable values of the ZnCdSe optical constants, there must have been some other deficiency in our model.
To begin, the issue of penetration depth should have been addressed before these samples were chosen. The amount of light that penetrates an absorbing layer decreases exponentially with the thickness of the layer. Table 2 shows that for thicker samples, light at higher energies could not penetrate to the layer of interest and back to the detector. Thus the fit was insensitive to the optical properties of the ZnCdSe layer.

The data we used for the ZnSe optical properties was acquired not from a ready table of values, but by manually extracting data points from a published graph and using these as the basis for our model. There exists a fair amount of variation in the reported dielectric function of ZnSe in the literature (Ref. 3); so there exists the possibility that the data we used was simply incorrect.

It is also possible that our samples, assumed to be optically perfect, were in fact deficient in one of several ways. The layers may indeed vary in thickness within a single sample; some “grading” within single layers may exist; the nominal number of layers could be simply wrong. Although these things are possible, the dependability of MBE and the experience of our colleagues at Notre Dame make them rather unlikely.

At this point, the most reasonable explanation for our deficient fits is that our ZnSe data is incorrect. The next stage of this project is to acquire a good table of values for ZnSe and try the fits again.

ACKNOWLEDGEMENTS

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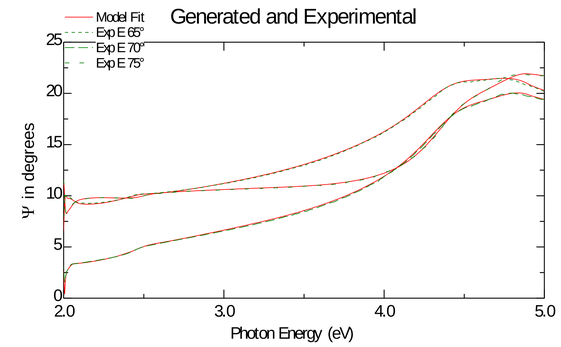
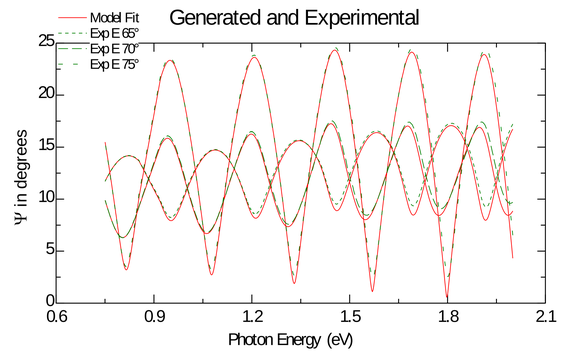
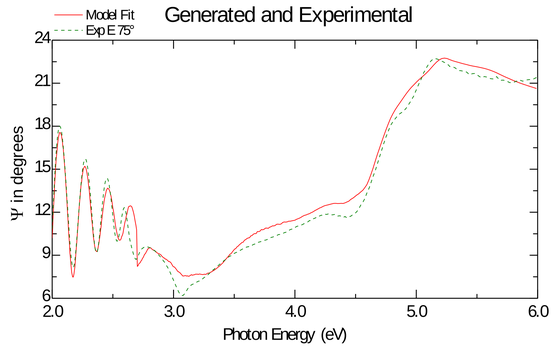


Graph 1. Sample fit for bulk ZnCdSe. Note the excellent correlation between our model and the experimental data.



Graph 2. Fitting for the thickness of the superlattice layers in the transparent region.



Graph 3. A typical fit for a superlattice structure over the full energy spectrum. The correlation between model and experiment exists but cannot be called adequate.

Sample Name	%Cd in ZnCdSe layer	ZnSe nominal layer thickness (nm)	ZnCdSe nominal layer thickness (nm)	Number of Periods
971003A	26.0	15	3	60
971003B	26.0	30	6	30
971006A	26.0	60	12	15
980127A	57.4	15	3	60
980127B	57.4	30	30	30
980127C	57.4	60	60	15
980115D	50.1	5.6	5.6	80

Table 1. The details of the samples chosen. The first and second groups of three constitute the two series of samples. The final sample was analyzed because the very thin layers should obviate the problem of penetration depth.